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CERTIFICATION ANALYSIS  
APOLLO SPACECRAFT 101 HEAT SHIELD ADEQUACY  
FOR AS 205/101 MISSION

JUNE 1968

Contract NAS9-150, S/A 300, Exhibit "I" Paragraph 7.3

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# TECHNICAL REPORT INDEX/ABSTRACT

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## ABSTRACT

The thermal adequacy of Apollo Spacecraft 101 Command Module for the AS 205/101 mission is evaluated by quantitative comparison of Spacecraft 101 entry heating environment with Block I flight test and design environments. The effects of configurational differences (between the Block II design of Spacecraft 101 and the flight tested Block I design) on entry heating and thermal adequacy of the heat shield system are specifically considered in this evaluation.

ABSTRACT

The thermal adequacy of Apollo Spacecraft 101 Command Module for the AS 205/101 mission is evaluated by quantitative comparison of Spacecraft 101 entry heating environment with Block I flight test and design environments. The effects of configurational differences (between the Block II design of Spacecraft 101 and the flight tested Block I design) on entry heating and thermal adequacy of the heat shield system are specifically considered in this evaluation.

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## 1.0 INTRODUCTION

Apollo Spacecraft 101 is the first of the Block II series that will experience Earth atmospheric reentry. Some configurational differences exist between the Block II design and the successfully recovered Spacecraft 009, 011, 017, and 020 that are basically of the Block I design (Spacecraft 020 was flight tested with a Block II unified hatch design). The thermal adequacy of Spacecraft 101, as influenced by the configurational differences between the Block I and Block II designs, must be certified prior to the AS 205/101 mission in accordance with Apollo requirements.<sup>(1)</sup> This report provides the formal documentation on which this certification is based. This documentation is supplemental to the successful flight tests of Spacecraft 017 and 020 as well as Spacecraft 009 and 011 which demonstrated thermal adequacy for Earth orbital entries. The configurational differences between the Block I and Block II designs that may affect entry heating and thermal response are as follows:

1. Elimination of the Block I CSM umbilical
2. Truncation of the Block II forward heat shield
3. Installation of the Block II unified crew hatch.

These design changes require certification as to the thermal adequacy of Spacecraft 101 for the AS 205/101 mission.

The entry heating environments of the planned SPS and back up RCS deorbit entries are quantitatively compared with the design heating environments and those experienced by Spacecraft 017 and 020; the effects of configurational differences are defined and the thermal adequacy of Spacecraft 101 is evaluated in terms of Block I flight test results and design allowables. It is concluded that Spacecraft 101 is thermally adequate for the AS 205/101 mission and can be so certified.

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<sup>(1)</sup> Certification Analysis Requirement Number 027002, "Spacecraft 101 Command Module Heat Shield Certification," dated January 24, 1968

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2.0 ENTRY TRAJECTORY FOR AS 205/101 MISSION

The planned entry trajectory for the AS 205/101 mission is an SPS deorbit entry with a 1900 nm range. At the atmosphere entry interface (400,000 feet), the inertial velocity is 25,840 feet per second; the initial flight path angle is -1.5 degrees. The planned entry trajectory is calculated for a Command Module weight of 12,576 pounds and a lift to drag ratio of 0.296, corresponding to a flight angle-of-attack of 160.4 degrees.

The back up entry trajectory is a RCS deorbit, G & N entry with a 2631 nm range. For this entry the initial flight path angle is -0.826 degrees; the inertial velocity is 25,938 feet per second. The trim angle-of-attack, lift to drag ratio, and spacecraft weight are unchanged from that of the planned mission entry.

Velocity and altitude time histories for the planned SPS and back up RCS deorbit entries<sup>(2)</sup> are presented in Figures 1 and 2, respectively.

---

(2) Data transmittal from J. Pavlosky, Manager, Thermal Protection Subsystem, Manned Spacecraft Center, Houston, Texas. Entry trajectories for AS 205/101 mission received by datafax June 14, 1968.

## 3.0 ENTRY HEATING

Reference heating histories for the AS 205/101 planned and back up entries (SPS and RCS deorbits) are illustrated by Figure 3. The reference heating represents the surface aerodynamic convective heat flux that would be experienced at the aft heat shield center ( $Z_c, Y_c=0$ ) with the spacecraft entering at a flight angle-of-attack of 180 degrees.

Calculated values of the maximum heating rates and integrated heat loads are shown in Table 1 for representative heat shield locations. These heating distribution data are shown for both the SPS and RCS deorbit trajectories. Compared with these SC 101 data are maximum heating rates and heating loads calculated for the entries as experienced by Spacecraft 017 and 020. The same analytical methods were employed in the heating calculations for the different spacecraft compared.

Configurational differences exist between Spacecraft 101, 017, and 020. Spacecraft 101 is a Block II configuration having a truncated forward heat shield and is without the protruding Block I CSM umbilical and the umbilical ramp on the aft heat shield. The Block I configurations were different in that Spacecraft 020 was fitted with a Block II unified crew hatch assembly while Spacecraft 017 was flight tested with the Block I crew hatch design. The effect of these configurational differences on heating are as follows: (1) the truncated surface of the forward heat shield will experience heating characteristic, in level and load, to the separated wake region of the Block I design; (2) simultaneous removal of the Block I CSM umbilical and the umbilical ramp will not change the design heating levels or distribution in that the umbilical ramp was designed to cancel the protuberance heating effects caused by the Block I CSM umbilical; and (3) heating to the unified hatch installation is no greater than to other surfaces in the separated wake region. In summary, the configuration changes between Block I and II that will be flight tested for the first time on Spacecraft 101 will have either no effect or will have the effect of lowering heating level (locally) below that of the Block I design.

With reference to Table 1, it is noted that the RCS deorbit entry will experience a slightly more severe heating environment than the planned SPS deorbit entry with the maximum heating point rate peaking at 60.5 Btu/ft<sup>2</sup>-sec and 45.3 Btu/ft<sup>2</sup>-sec for the RCS and SPS deorbit entries, respectively. The integrated heat loads at the maximum heating point for the two entries are very similar in level with the RCS deorbit entry being slightly higher at 14,536 Btu/ft<sup>2</sup> compared with 13,371 Btu/ft<sup>2</sup> for the SPS deorbit entry.

The most severe entry for Spacecraft 101 will develop a heating environment that is only a fraction of the heating experienced by Spacecraft 017 and 020; or a maximum heat load of 14,536 Btu/ft<sup>2</sup> compared with 36,160 Btu/ft<sup>2</sup> for Spacecraft 017 and 27,000 Btu/ft<sup>2</sup> for Spacecraft 020.



## 4.0 THERMAL RESPONSE

The thermal response of Spacecraft 101 heat shield ablator and component penetrations (i.e., CSM pads, antennas, etc.) will be less than that experienced by the successfully flight tested spacecraft, Spacecraft 017 and 020. Since both Spacecraft 017 and 020 have Block II ablator thicknesses, the thermal adequacy of the Command Module 101 ablator heat shield is readily demonstrated by the heating environment comparisons with the flight tested spacecraft as presented by Table 1 and discussed in Section 3.0.

As previously discussed, the absence of the Block I CSM umbilical (with which previous spacecraft have flown) will either lessen the local heating environment or have no effect. As such the thermal response of Command Module 101 will not be adversely affected by the absence of the Block I umbilical and the umbilical ramp located on the aft heat shield; therefore, the heat shield adequacy in this local area is established by the Table 1 heating comparisons since the design method<sup>(3)</sup> employed in determining ablator requirements in the affected reconfigured area is the same for Block II as was employed for Spacecraft 017 and 020.

The thermal adequacy of the truncated forward heat shield is illustrated by the comparison of the design heat load<sup>(4)</sup> (corresponding to the HL-1 lunar return trajectory) with the Spacecraft 101 heat loads to the forward heat shield (flat apex) as presented by Figure 4. The most severe Spacecraft 101 entry will cause the flat apex to experience a heat load of 585 Btu/ft<sup>2</sup> compared to the design heat load to this area of 3,520 Btu/ft<sup>2</sup>. For reference, Figure 4 includes temperature responses, at representative in-depth locations, that are calculated for the maximum heat load design trajectory; the response of Spacecraft 101 will be less than the design allowables as indicated by the considerably less severe heating environment for Spacecraft 101.

The thermal response in the area of the Spacecraft 101 unified crew hatch will have a relationship to the design allowable as has been illustrated for the forward heat shield flat apex since both of these areas are within the separated wake region and, therefore, have the same heating environment. The thermal adequacy of the unified crew hatch installation has been demonstrated by the Spacecraft 020 flight test; for this entry the heat load in the separated wake region is calculated as 945 Btu/ft<sup>2</sup> compared with 585 Btu/ft<sup>2</sup> for the most severe Spacecraft 101 entry (compared with measured data from Spacecraft 020, the calculated heat loads are conservative by a factor of approximately two). The temperature rise from entry heating can, therefore, be expected to be less on Spacecraft 101 than experienced on Spacecraft 020.

(3) Avco Corp., "Apollo Heat Shield: Block II Final Thermodynamics Report (U)," (6 Vols.) 15 April 1967

(4) "Design Criteria Trajectories and Heating Rates for Apollo Command Module Heat Shield," (7 Vols.), North American Rockwell Report SID 65-768, 24 May 1965 (Confidential)

## 5.0 CONCLUSIONS

The entry heating environment and thermal response of Spacecraft 101 will be substantially less for the AS 205/101 mission than for the lunar return design conditions<sup>(4)</sup> or for the environments experienced by Spacecraft 017 and 020 during their respective entries. The Block II configuration, as it differs from the flight tested Block I designs (i.e., truncation of the forward heat shield, elimination of the protruding Block I umbilical, and the redesigned crew hatch which was also flight tested on Spacecraft 020) is demonstrated as being thermally adequate for the AS 205/101 mission entries as determined for either the planned SPS deorbit or back up RCS deorbit entry.

FIGURE 1. TRAJECTORY FOR PLANNED AS 205/101 SPS DIRECT ENTRY

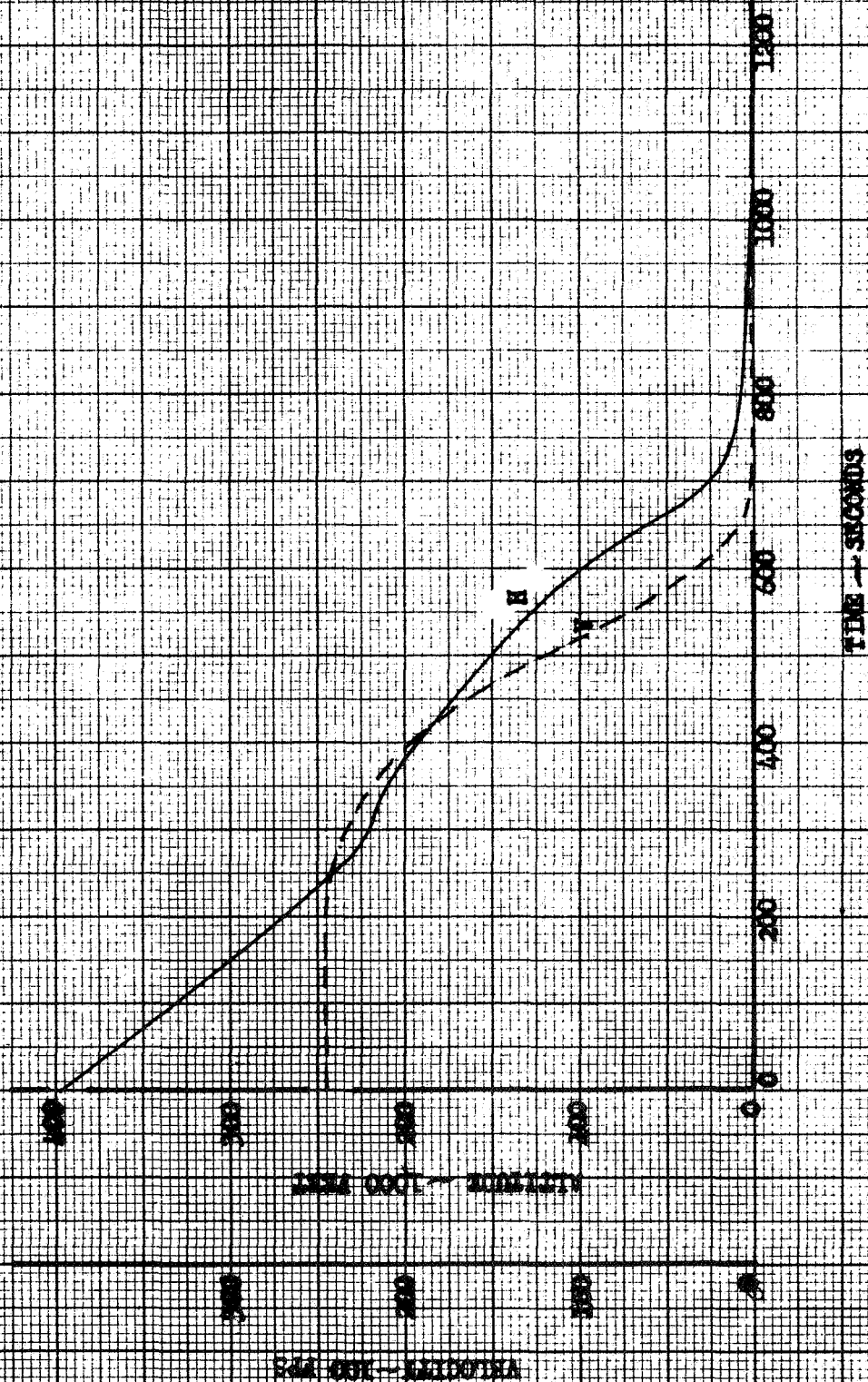






FIGURE 3. REFERENCE HEATING HISTORIES FOR AS 205/101 SPS AND RCS DEGRIT ENTRIES

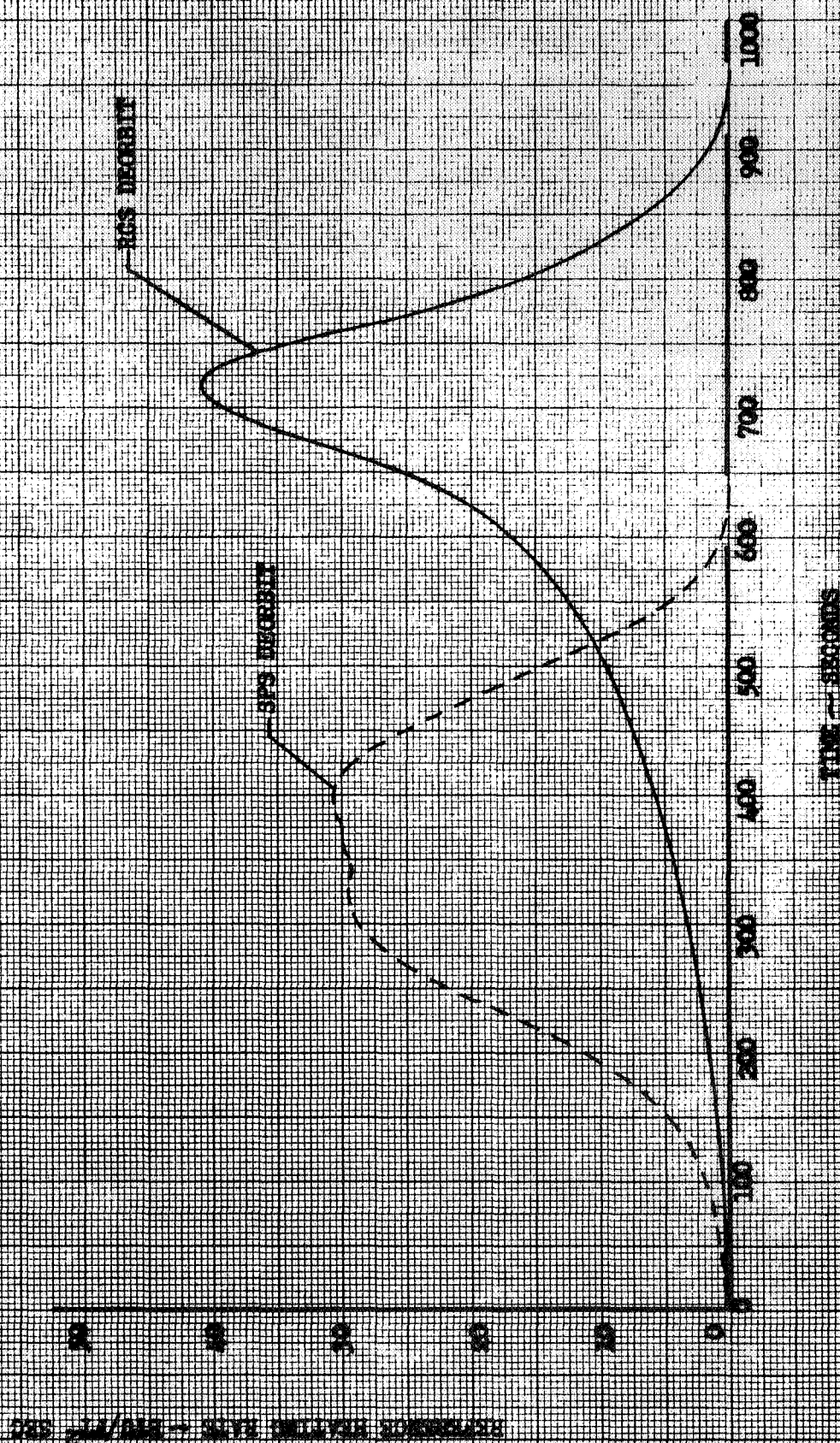
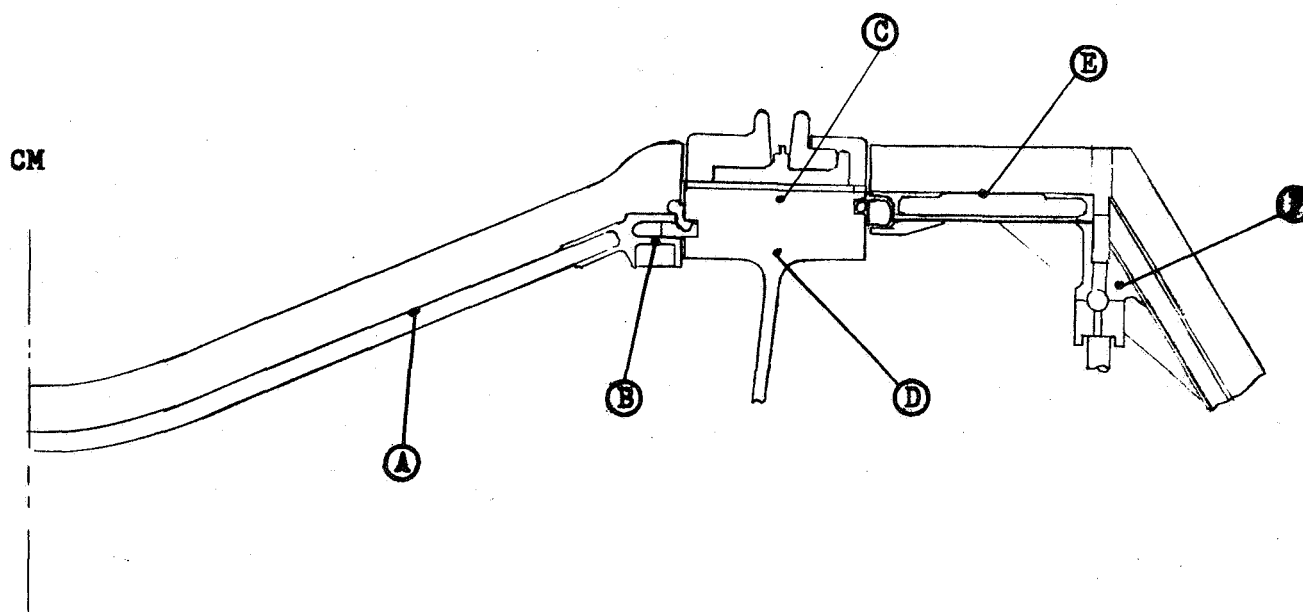


FIGURE 4. HEATING ENVIRONMENT AND THERMAL RESPONSE OF THE TRUNCATED FORWARD HEAT SHIELD



	Temperature Rise (F°)	Entry Heat Load (Btu/ft <sup>2</sup> )		
		HL-1 Design	SC 101 Preflight	
			SPS	RCS
Ⓐ	185	3520	546.	585.
Ⓑ	100			
Ⓒ	385			
Ⓓ	60			
Ⓔ	165			
Ⓕ	70			

TABLE 1. COMPARISON OF SPACECRAFT 101 ENTRY HEATING WITH SPACECRAFT 017, SPACECRAFT 020, AND BLOCK II DESIGN ENVIRONMENTS

Integrated Heat Load

Location $\theta_c$ $X_c$ $Y_c$ $Z_c$ Reference Body Point		SC 101 (AS 205/101)				SC 017		SC 020		Design Criteria			
		SPS Deorbit		RCS Deorbit		$Q_c$	$Q_r$	$Q_c$	$Q_r$	HL-1		HR-1	
		$Q_c$	$Q_r$	$Q_c$	$Q_r$					$Q_c$	$Q_r$	$Q_c$	$Q_r$
		8,877	~0	9,495	~0	16,700	6,780	13,830	1,020	26,500	17,100	16,500	20,000
		13,371	~0	14,536	~0	30,870	5,290	26,080	920	52,700	12,600	25,800	13,100
		7,715	~0	8,868	~0	17,510	2,300	13,140	590	18,500	4,260	15,500	3,550
90	68.0	712	~0	761	~0	2,390	~0	1,500	~0	3,560	~0	1,970	~0
270	Leeside	546	~0	585	~0	1,120	~0	945	~0	3,520	~0	1,890	~0
Maximum Heating Rate													
		$\dot{q}_c$	$\dot{q}_r$	$\dot{q}_c$	$\dot{q}_r$	$\dot{q}_c$	$\dot{q}_r$	$\dot{q}_c$	$\dot{q}_r$	$\dot{q}_c$	$\dot{q}_r$	$\dot{q}_c$	$\dot{q}_r$
	100	27.8	~0	37.1	~0	143.	250.	94.	13.	108.	220.	546.	1550.
	200	45.3	~0	60.5	~0	280.	193.	184.	11.	219.	148.	553.	990.
	210	36.9*	~0	53.5*	~0	292.	72.	171.	6.	68.	32.	458.	142.
	356	2.3	~0	3.1	~0	21.	~0	10.	~0	15.	~0	70.	~0
	Leeside	1.8	~0	2.5	~0	10.	~0	6.7	~0	20.	~0	37.	~0

Q = Heat Load, Btu/ft<sup>2</sup>

$\dot{q}$  = Heat Rate, Btu/ft<sup>2</sup>-sec

Subscripts

c = Convective Heat Transfer

r = Radiative Heat Transfer

Superscripts

\*Turbulent Boundary Layer

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